Nasa CR 65457

FIRST QUARTERLY REPORT

PHASE B

Thin-Film Personal Communications and Telemetry System (TFPCTS)

Contract No. NAS 9-3924

Submitted to

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
Houston, Texas

MELPAR, INC.
7700 Arlington Boulevard
Falls Church, Virginia 22046

First Quarterly Report

Phase B

THIN-FILM PERSONAL COMMUNICATIONS AND TELEMETRY SYSTEM (TFPCTS)

For the period of March 24, 1966 to June 24, 1966

Contract No. NAS 9-3924

Submitted to

National Aeronautics and Space Administration
Manned Spacecraft Center
Houston, Texas

July 1966

Melpar, Inc.
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LIST OF ILLUSTRATIONS

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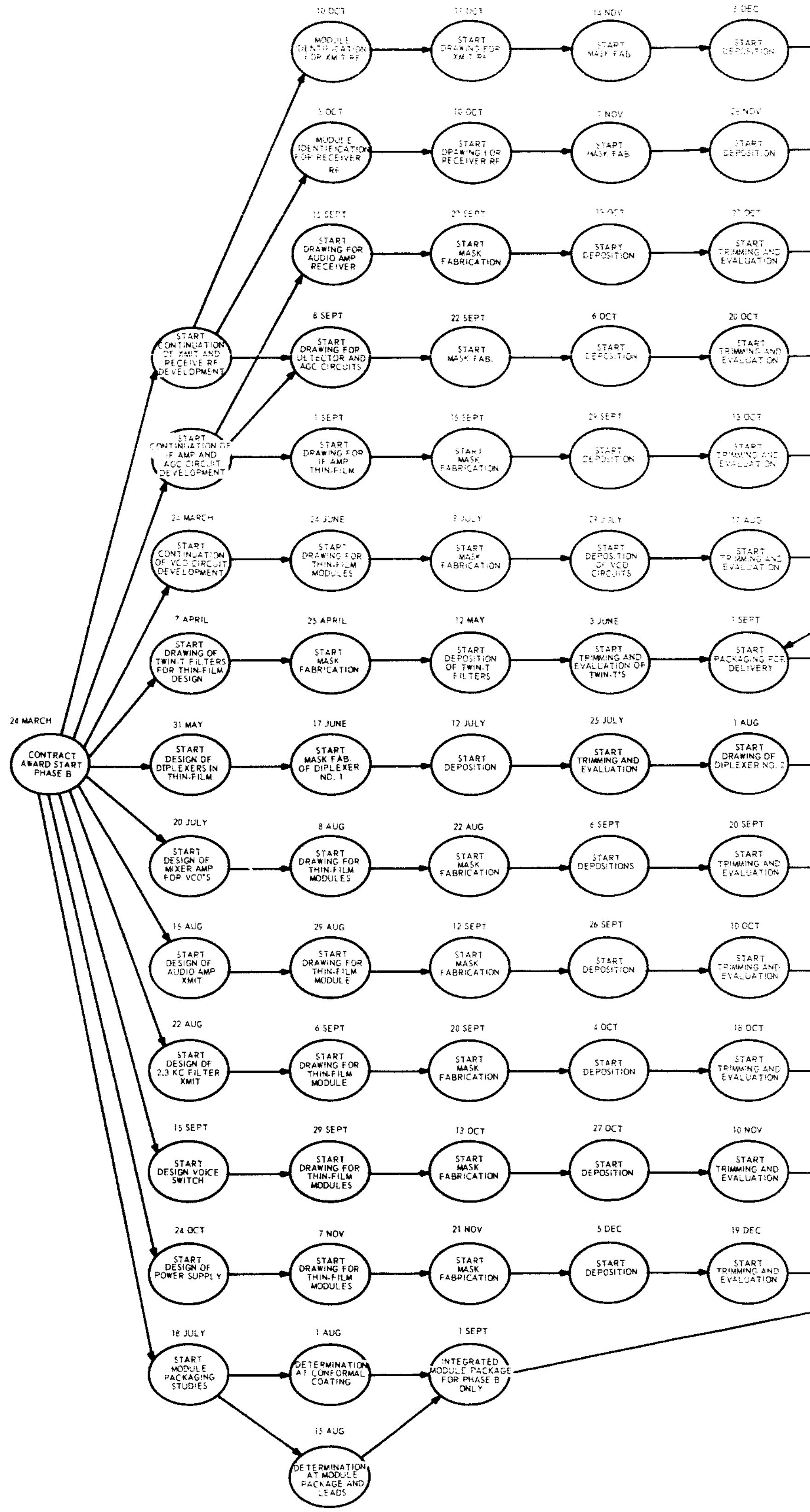
1. INTRODUCTION

Phase B of the subject contract (NAS 9-3924) was initiated on 24 March 1966. Melpar submits this first quarterly report in compliance with the contract. The ultimate task objective is to construct a thin-film personal communication and telemetry system. During Phase B, the objective is to design and construct the circuit modules which will be used in Phase C to package the total system. Each module is designed to be as completely thin-film as possible.

A PERT chart for Phase B was shown in the proposal; a revised chart is given in figure 1 which will be used for scheduling and reporting. Progress on the chart is shown by heavy lines and the anticipated completion dates are shown at each step. In general, each line on the chart represents a circuit module. The development of the modules is staggered to avoid a pile-up of work at any given process step. All of the processing is scheduled for completion before 1 January 1967. This will allow three months to evaluate the system performance and, if necessary, time for reprocessing defective designs.

During the first quarter, the transceiver design was reviewed and the individual thin-film modules were identified. The twin-T, VCO, and diplexer modules were designed in thin-film form and are now in the process of being fabricated. A set of three twin-T filters is completed and has been on life test for one month. Depositions of VCO substrates and diplexer substrates should be in process within the next monthly report interval.


24 MARCH
CONTRACT AWARD START PHASE B
7 APRIL
START DRAWING OF TWIN-T FILTERS FOR THIN-FILM DESIGN
25 APRIL
START MASK FABRICATION
12 MAY
START DEPOSITION OF TWIN-T FILTERS
3 JUNE
START TRIMMING AND EVALUATION OF TWIN-T'S
1 SEPT
START PACKAGING FOR DELIVERY
31 MAY
START DESIGN OF DIPLEXERS IN THIN-FILM
17 JUNE
START MASK FAB. OF DIPLEXER NO. 1
12 JULY
START DEPOSITION
25 JULY
START TRIMMING AND EVALUATION
1 AUG
START DRAWING OF DIPLEXER NO. 2
20 JULY
START DESIGN OF MIXER AMP FOR VCO'S
8 AUG
START DRAWING FOR THIN-FILM MODULES
22 AUG
START MASK FABRICATION
6 SEPT
START DEPOSITIONS
20 SEPT
START TRIMMING AND EVALUATION
15 AUG
START DESIGN OF AUDIO AMP XMIT
29 AUG
START DRAWING FOR THIN-FILM MODULE
12 SEPT
START MASK FABRICATION
26 SEPT
START DEPOSITION
10 OCT
START TRIMMING AND EVALUATION
22 AUG
START DESIGN OF 2.3 KC FILTER XMIT
6 SEPT
START DRAWING FOR THIN-FILM MODULE
20 SEPT
START MASK FABRICATION
4 OCT
START DEPOSITION
18 OCT
START TRIMMING AND EVALUATION
15 SEPT
START DESIGN VOICE SWITCH
29 SEPT
START DRAWING FOR THIN-FILM MODULES
13 OCT
START MASK FABRICATION
27 OCT
START DEPOSITION
10 NOV
START TRIMMING AND EVALUATION
24 OCT
START DESIGN OF POWER SUPPLY
7 NOV
START DRAWING FOR THIN-FILM MODULES
21 NOV
START MASK FABRICATION
5 DEC
START DEPOSITION
19 DEC
START TRIMMING AND EVALUATION
18 JULY
START MODULE PACKAGING STUDIES
1 AUG
DETERMINATION AT CONFORMAL COATING
1 SEPT
INTEGRATED MODULE PACKAGE FOR PHASE B ONLY
15 AUG
DETERMINATION AT MODULE PACKAGE AND LEADS
6 SEPT
START DRAWING FOR DETECTOR AND AGC CIRCUITS
22 SEPT
START MASK FAB.
20 OCT
START TRIMMING AND EVALUATION
1 SEPT
START DRAWING FOR IF AMP THIN-FILM
START CONTINUATION OF XMIT AND RECEIVE RF DEVELOPMENT
START CONTINUATION OF IF AMP AND AGC CIRCUIT DEVELOPMENT
START CONTINUATION OF VCO CIRCUIT DEVELOPMENT
START DRAWING FOR THIN-FILM MODULES
START MASK FABRICATION
START DRAWING FOR AUDIO AMP RECEIVER
START MASK FABRICATION
START DEPOSITION
MODULE IDENTIFICATION FOR RECEIVER RF
START DRAWING FOR RECEIVER RF
START MASK FAB
START DEPOSITION
MODULE IDENTIFICATION FOR XMIT RF
START MASK FAB
START DEPOSITION

6-1

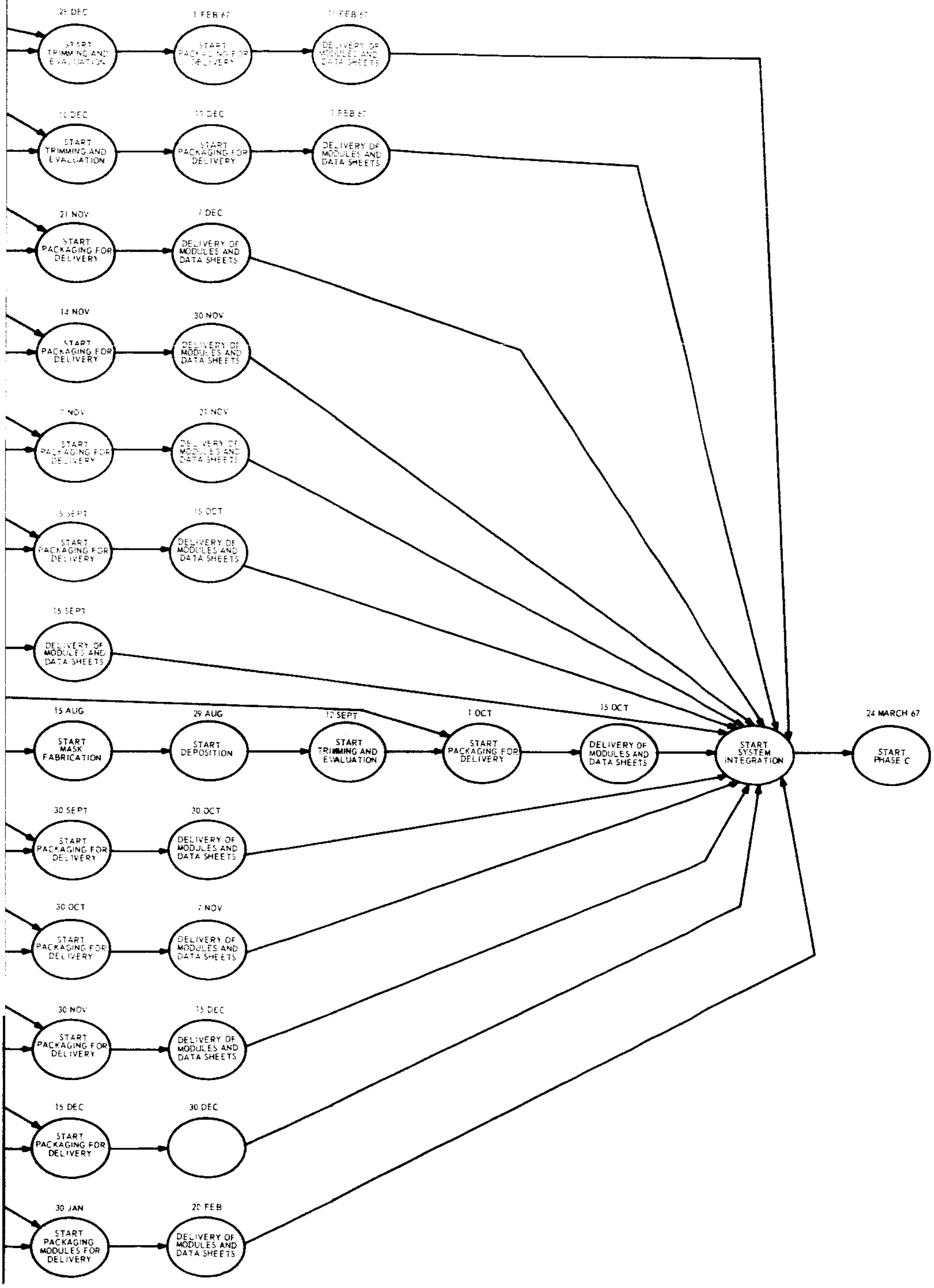


Figure 1. PERT Chart

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2. SYSTEM CONCEPT

A block diagram of the system is shown in figure 2. The secondary system is identical with the exception that the data channels are not included. To date, the secondary system has been considered as simplex but is now considered to be duplex and includes a diplexer.

The receiver local oscillator and the transmitter carrier frequencies are generated by tripling the output of a crystal oscillator. The i-f frequency is 0.5 mc which allows the use of RC coupled stages. At higher i-f frequencies, it would be necessary to use tuned coupling stages; in thin-film form the coils would not be practical at frequencies below 100 mc. The crystals are clamped to resonate at the 5th overtone of the fundamental (approximately 20 mc).

Modulation of the transmitter is accomplished with gate modulation on the low level r-f stages. This method again avoids the use of a transformer which would be beyond the range of thin-film capabilities. At present the low level r-f stages are commercial FET's and power output is provided with a conventional transistor. A full 150 mw r-f breadboard has been constructed. Maximum utilization of thin-films in the r-f section will require further circuit improvements; some of the coils in the present design are high Q (> 150) and, in two cases, the inductance is over 0.1 microhenry. The use of gate modulation eliminates the requirement for modulation power but increases the power required in the r-f stages. At present the efficiency of the output stages is approximately 30% at 150 mw r-f output.

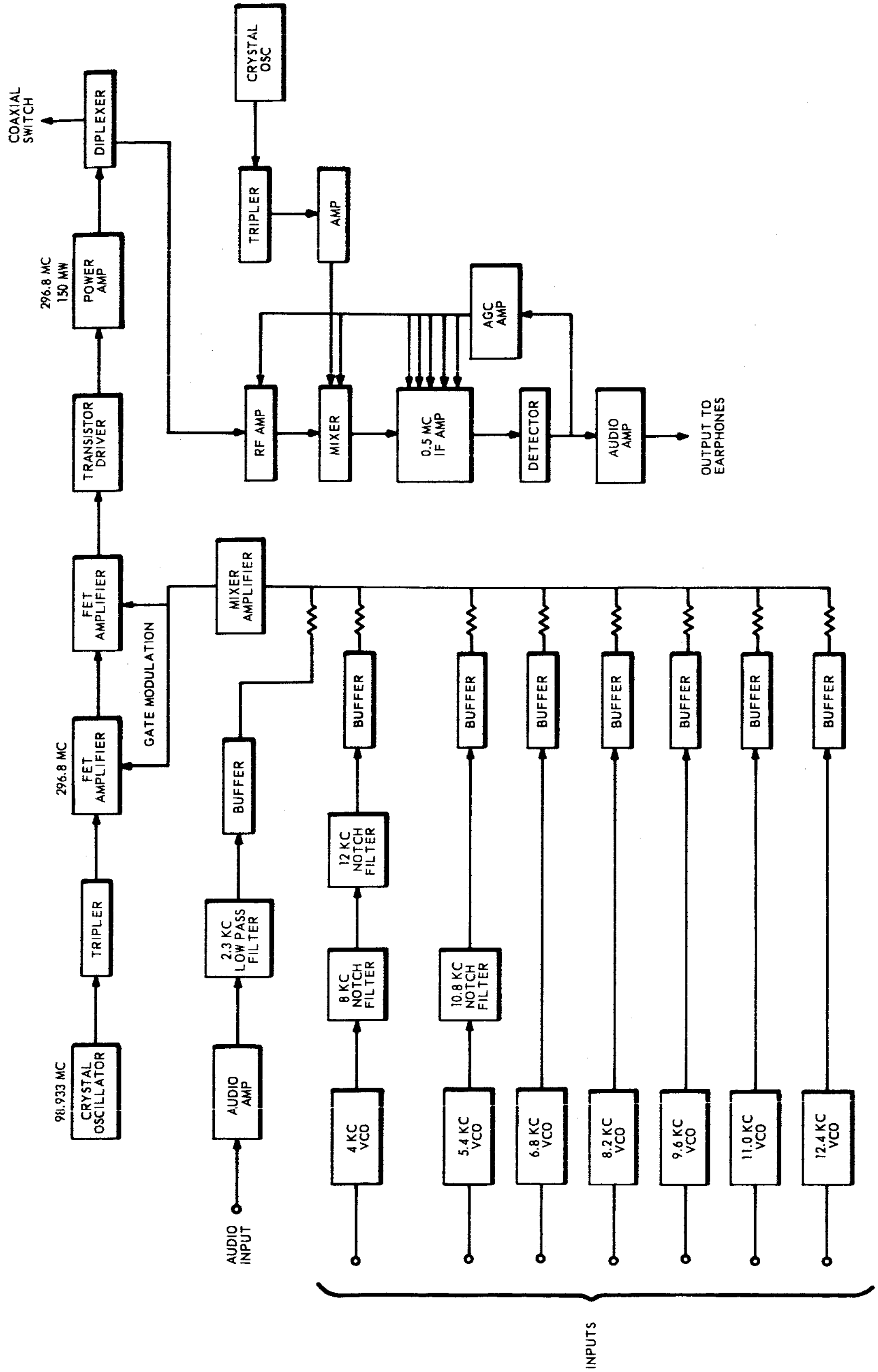
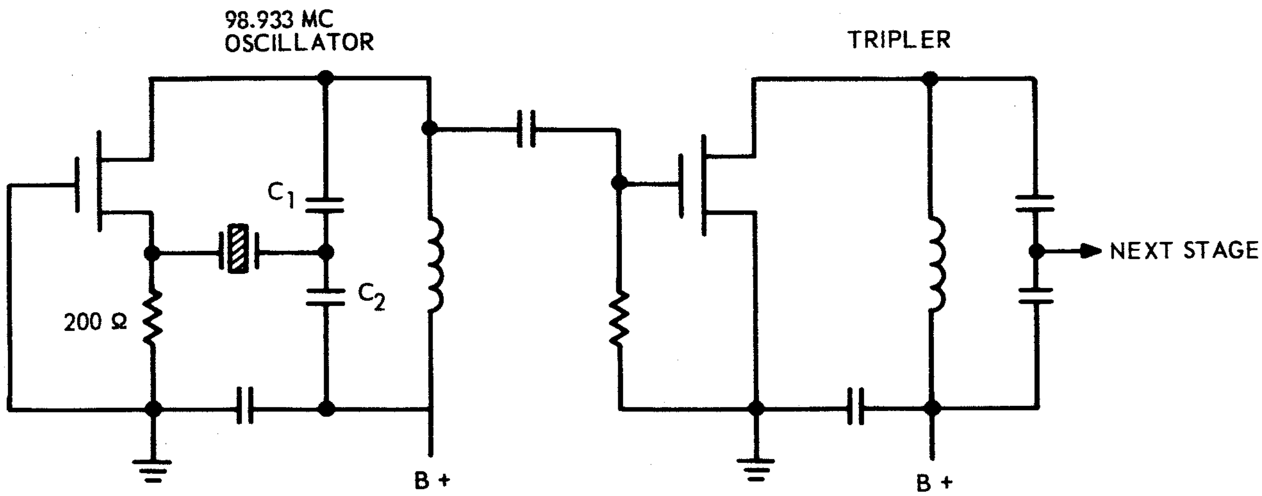


Figure 2. System Block Diagram

The oscillator-tripler circuit is shown in figure 3. The oscillator presently used is a grounded gate stage with the drain signal fed back to the source. For optimum transfer of power (minimum loss), the capacitor ratio $\left(\frac{C_s}{C_1+C_2}\right)^2$ should be nearly equal to the ratio of the drain resistance, (in this case, the crystal resistance at resonance in series with the input resistance at the source). The 200-ohm source resistance is chosen to make the loop gain slightly greater than one. The circuit can be made more insensitive to spurious component changes by shunting the crystal capacitance with a tuning inductance. A 0.5 microhenry inductor is required for this purpose, so that the more critical design is justified in thin-film form. A nonlinear amplifier provides frequency tripling with the amplifier output tuned to the third harmonic of the oscillator.

In the primary system, the modulation consists of seven VCO channels (75% of the modulation) and a voice channel (20% of the modulation). Full modulation of the FET's requires approximately a 3-volt peak-to-peak signal. After mixing, the complex VCO signal should have an rms value equal to $0.75 \times \frac{3}{2.8} = 0.8$ volt. The contribution from each VCO is then 0.3 volt rms. The summing network is designed to provide this 0.3 volt rms at the fundamental frequencies of the VCO's. Filter networks are added to eliminate the harmonic energies. Twin-T's are used on the lower channels and a single filter is used in the mixing circuit to reduce the energies caused by the harmonics of the higher channels.

A diplexer will be used to couple the transmitter and receiver to a 50-ohm antenna. The major function of the diplexer is to prevent the



$$\left(\frac{C^2}{C_1 + C_2}\right)^2 = \frac{r_p}{R_k + R_x} = 5$$

R_x = IMPEDANCE OF CRYSTAL AT F_o

Figure 3. Oscillator - Tripler

the transmit energy from disturbing the receiver performance. A discrete component filter system was constructed which offered 60-db attenuation. The thin-film version was designed with the same component values but the geometrical arrangement is considerably different. The evaluation of the diplexer will provide much of the information required to lay out the remainder of the r-f circuitry.

The receiver r-f consists of a single stage amplifier, a mixer, and the local oscillator. Circuitry for the local oscillator is identical with the transmitter oscillator-tripler. The r-f amplifier itself is simply a tuned amplifier with an input matching network. At present the matching network (50 to 1200 ohms) is an L section which uses a fairly large inductor. A capacitive divider network will be investigated to try to eliminate the inductor.

Selectivity in the receiver is largely due to the r-f tuned circuits. A 6-stage, RC-coupled, i-f amplifier is broadband at 0.5 mc center frequency. Additional selectivity may be added with an RC feedback filter around 1 or 3 stages of the intermediate frequency.

There are three voltages required to maintain AGC on the various stages in the receiver; i.e., the r-f amplifier, the mixer, and the intermediate frequency. AGC amplifiers are required to produce each of the signals, both because of the dc levels required and because of the amplitude.

3. TWIN-T FILTER MODULES

The function of the twin-T filters is to remove the harmonics of the low channel VCO's which would interfere with the higher channels. Thus the 4 kc and 5.4 kc VCO's will have harmonics at 8 kc, 12 kc and 10.8 kc which would interfere with the higher channels. A single filter does not have sufficient bandwidth to reject the harmonics over the total deviated bandwidth. To obtain the required bandwidth, two twin-T's are stagger-tuned. A single substrate (1" x 1") is used for a staggered tuned pair.

During the first quarter, a set of three filters was completed. These units are now being used to test conformal coatings, and to evaluate the electrical performance. The yield of filters to date has been rather low due to problems in depositing capacitors; this is a normal problem at the beginning of a new deposition process and will improve with better process control.

On a completed filter, the individual capacitors cannot be measured directly. The capacitors are measured and then the value is corrected by calculating the effect of the remaining circuitry. When the capacitor values are known, the individual resistor values can be calculated. This is shown schematically in figure 4. When a 2000 pf capacitor is measured at 10 kc, there is a correction factor of approximately 7%.

Resistor trimming is accomplished in two steps. On a newly deposited substrate, parts of the resistor material are shorted so that all resistors measure less than any desired final value. By selectively cutting shorting bars, the resistance is raised to within 5% of its final value. During the trim operation, the substrate is mounted on a stable platform where

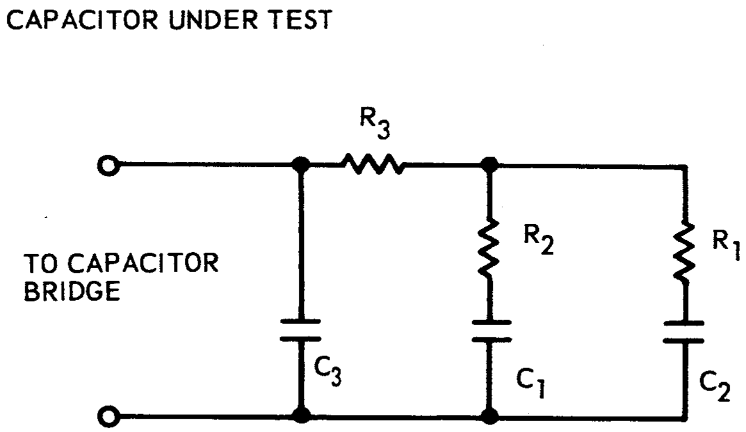


Figure 4. Equivalent Circuit of Twin-T Network when Measuring a Capacitor

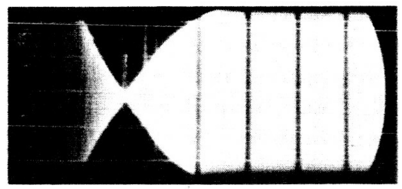
it can be viewed with the aid of a microscope. Electrical contact is made with needle probes which are, in turn, connected to a precision Wheatstone bridge and galvanometer. For the final trimming, a diamond scribe attached to a micromanipulator is used to notch the resistor material while observing the null indication on the galvanometer.

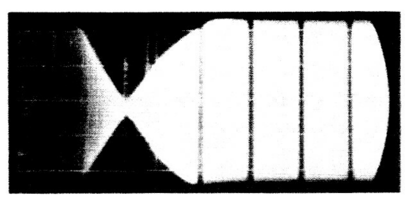
These filters have been fabricated using this procedure and, in all three, the results were excellent. The first filter was designed to notch the 2nd harmonic of the 4-kc VCO. Taking into account the deviated bandwidth, the filter should reject frequencies between 7.6 and 8.4 kc. The constructed filter maintains a 33-db attentuation (below the 4-kc level) in this interval. Since the second harmonic of a symmetrical square wave is small to begin with, 33-db attenuation is sufficient. Attenuation values for third harmonics measure better than 41 db. Figure 5 shows a typical response curve for an 8-kc filter.

4. VCO MODULES

It was originally planned to deposit two VCO's on a substrate. During the layout design it became apparent that this would not be possible due to the large number of components and because it is necessary to allow for trimming bars on the resistors. This will increase the total number of modules to 33.

As with the filter modules, it will be advantageous to fabricate the four VCO modules with a single set of masks. To do this it is necessary to allow for a large range of resistor trimming. The trimming must be capable of allowing for both the correct RC product and the variations in bias required for the transistors.





SCALE: H ≈ 2.5KC/DIVISION, MARKER AT 8 KC

V = 0.5V/DIVISION

Figure 5. Twin-T Filter Frequency Response

The VCO's fabricated to date have used discrete components including commercial FET's. An aging or "burn-in" process is being investigated for the thin-film active devices in order to stabilize the drain current at constant bias voltage. After the aging process, the resistors can be trimmed while the circuit is operating. In this way, a frequency counter can be used to monitor the trimming operation.

5. MASKING

A complete set of masking drawings are included for the modules designed to date (figures 6 to 24). The list of illustrations in the beginning of the report will serve as a reference to the drawings. All of the drawings are at a 4:1 scale.

6. CIRCUIT MODULES

The following revised list represents the complete set of modules (power supply excepted) that will be required for the transceiver:

Module No. 1 - Audio amplifier (transmitter)

2 - 2.3 kc low-pass filter

3 - Voice-operated switch

4 - 4 kc VCO

5 - 5.4 kc VCO

6 - 8.8 kc VCO

7 - 8.2 kc VCO

8 - 9.6 kc VCO

9 - 11 kc VCO

10 - 12.4 kc VCO

11 - Staggered pair 8-kc twin-T notch filter

Module No.	12	-	Staggered pair 12 kc twin-T notch filter
	13	-	Staggered pair 10.8 kc twin-T notch filter
	14	-	Diplexer primary system
	15*	-	Diplexer primary system
	16	-	Diplexer secondary system
	17*	-	Diplexer secondary system
	18	-	Mixer amplifier
	19*	-	Transmitting R-F and modulator
	20*	-	Receiver R-F and mixer
	21	-	I-F amplifier (1st half)
	22	-	I-F amplifier (2nd half)
	23	-	Detector and AGC
	24	-	Audio amplifier (receiver)
	25	-	Same as No. 1 module
	26	-	Same as No. 3 module
	27	-	Same as No. 18 module
	28	-	Same as No. 19 module
	29	-	Same as No. 20 module
	30	-	Same as No. 21 module
	31	-	Same as No. 22 module
	32	-	Same as No. 23 module
	33	-	Same as No. 24 module

* All modules are 1" x 1" except 15, 17, 19, 20

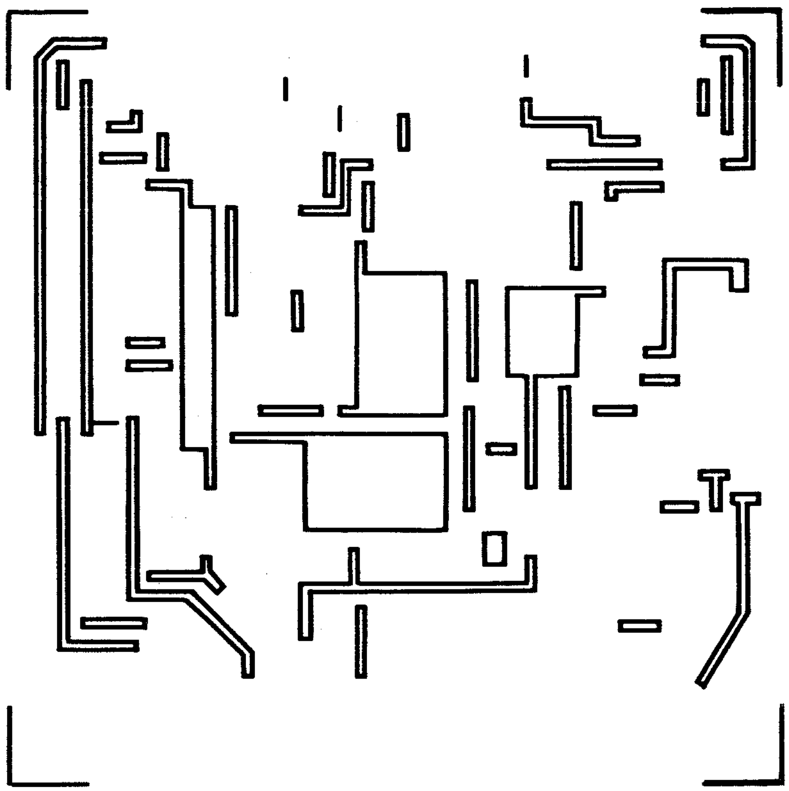


Figure 6. Voltage-Controlled Oscillator First Conductor Mask No. 1

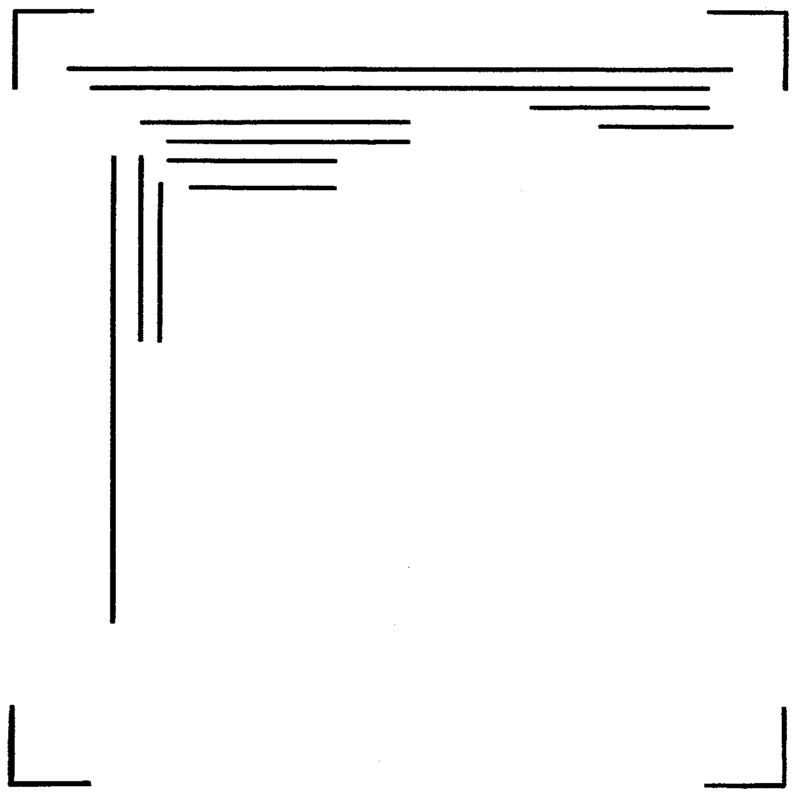


Figure 7. Voltage-Controlled Oscillator Resistors (High Value) Mask No. 2

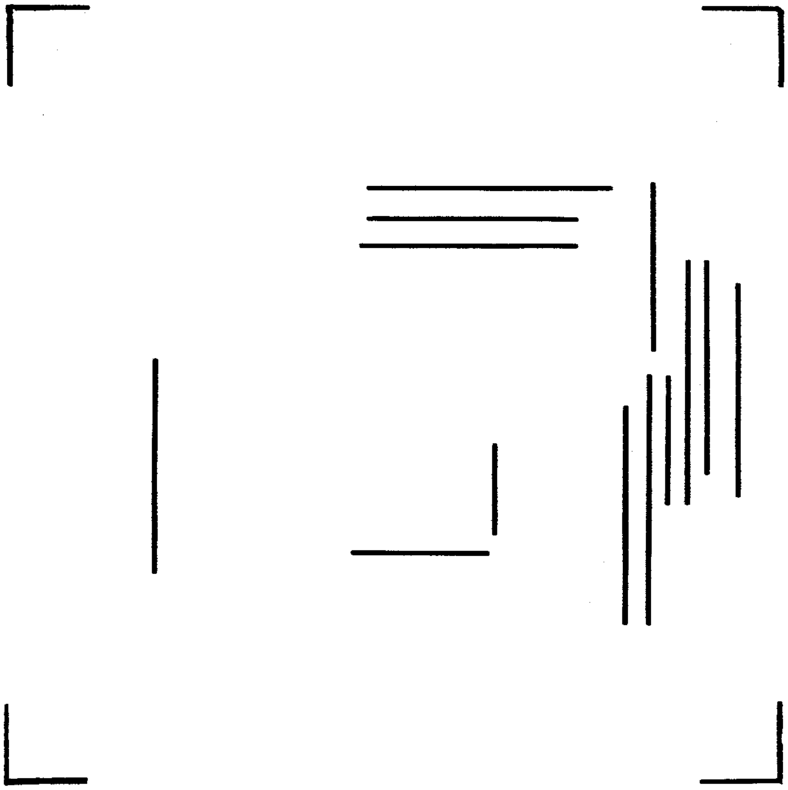


Figure 8. Voltage-Controlled Oscillator Resistors (Low-Value) Mask No. 3

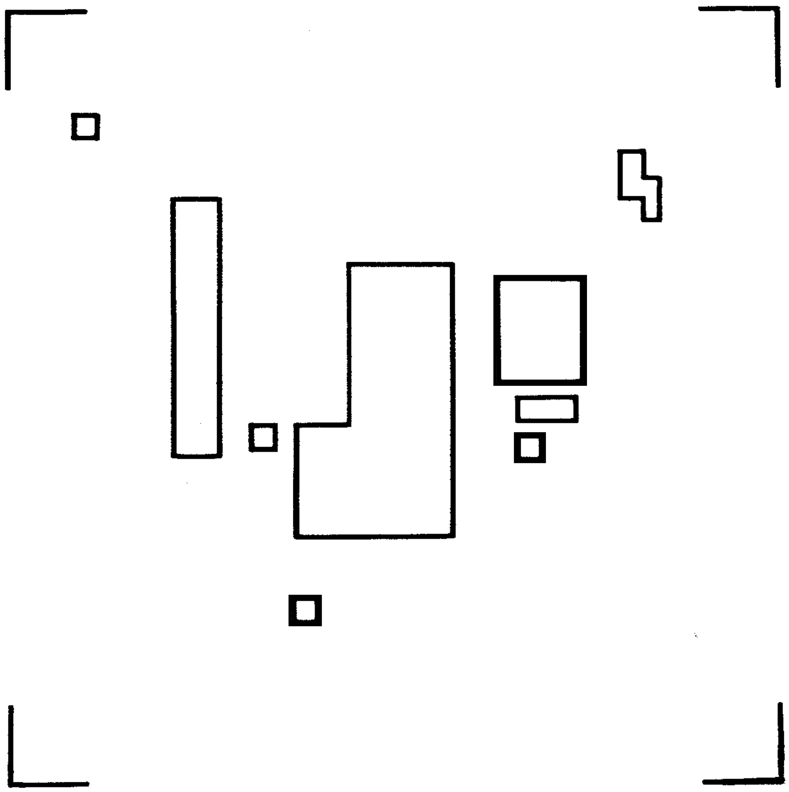


Figure 9. Voltage-Controlled Oscillator Dielectric Mask No. 4

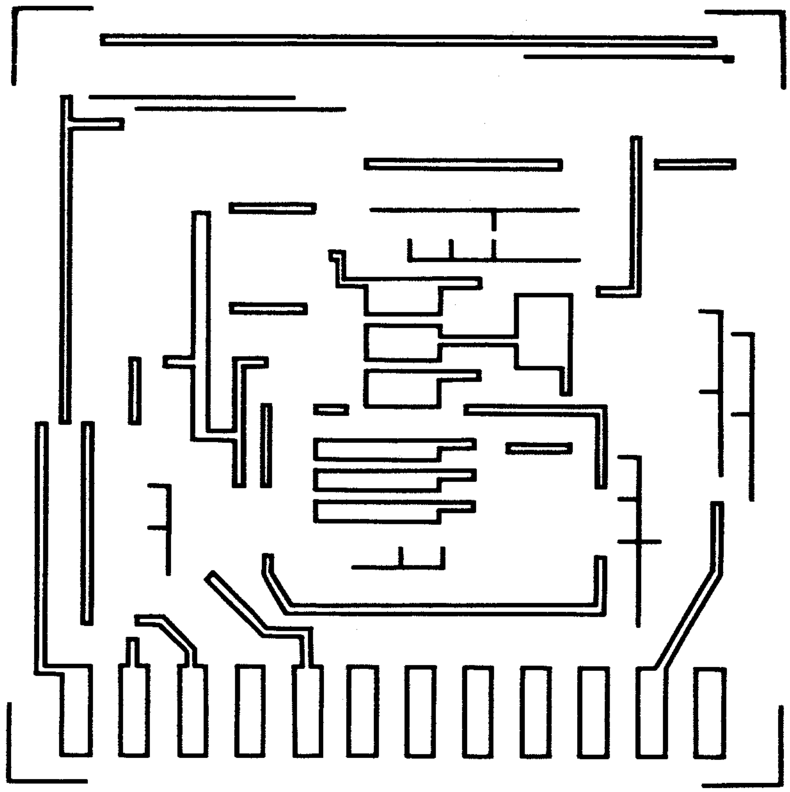


Figure 10. Voltage-Controlled Oscillator Second Conductor Mask No. 5

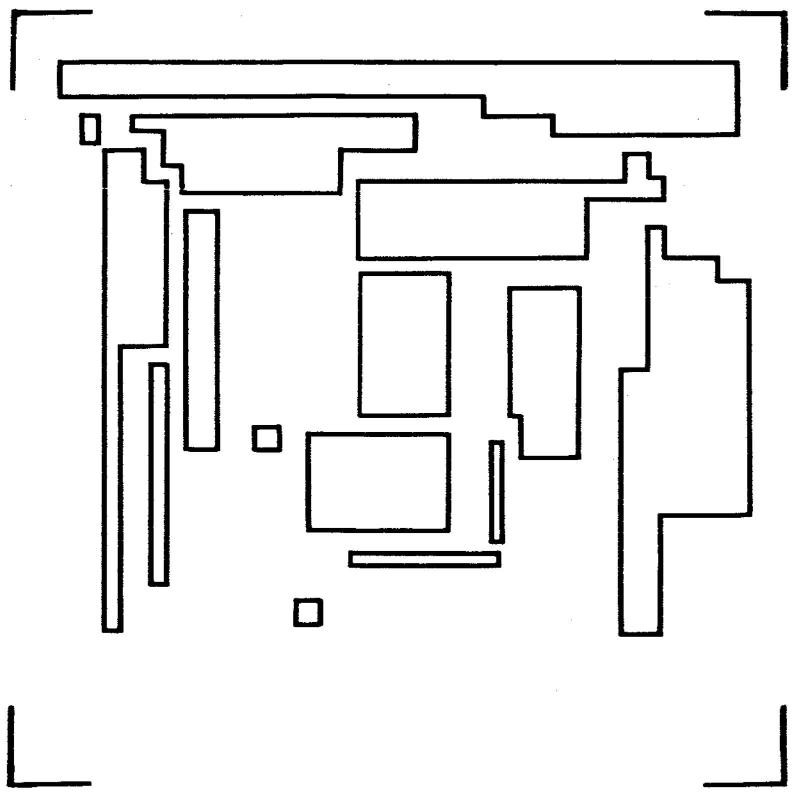


Figure 11. Voltage-Controlled Oscillator Protective Coating Mask No. 6

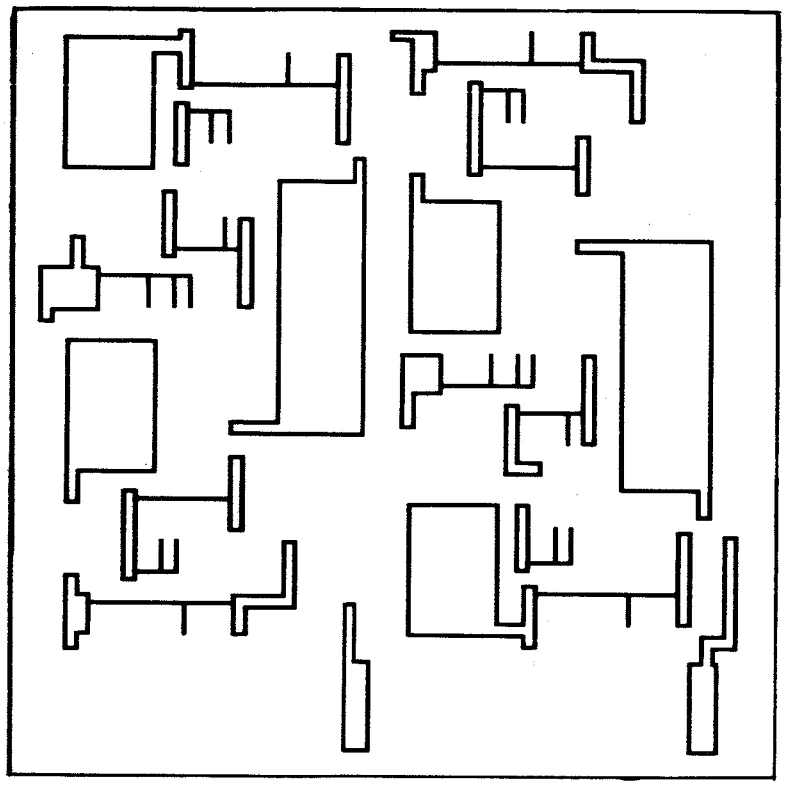


Figure 12. Twin-T Filter First Conductor Mask No. 1

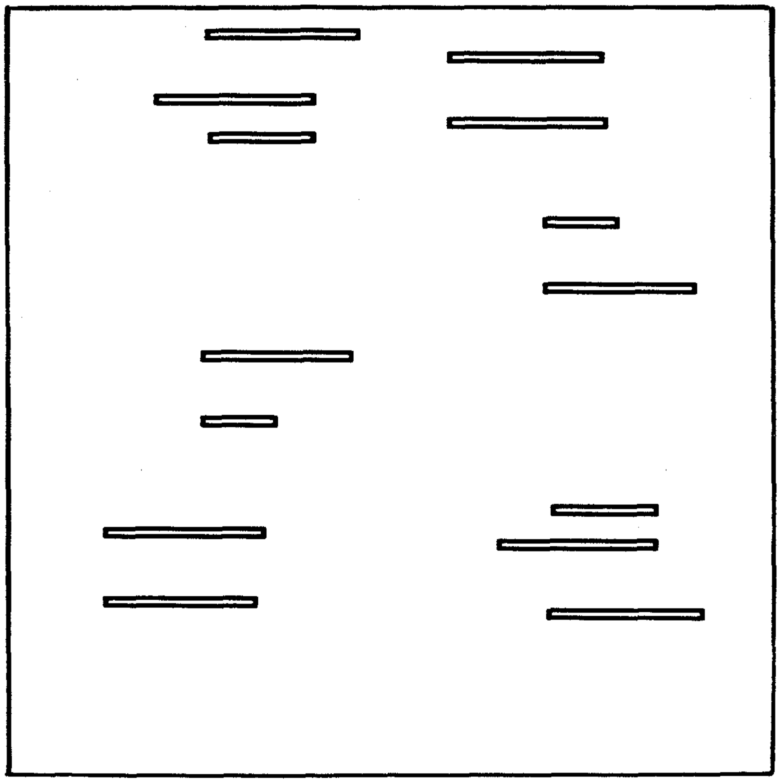


Figure 13. Twin-T Filter Resistor Mask No. 2

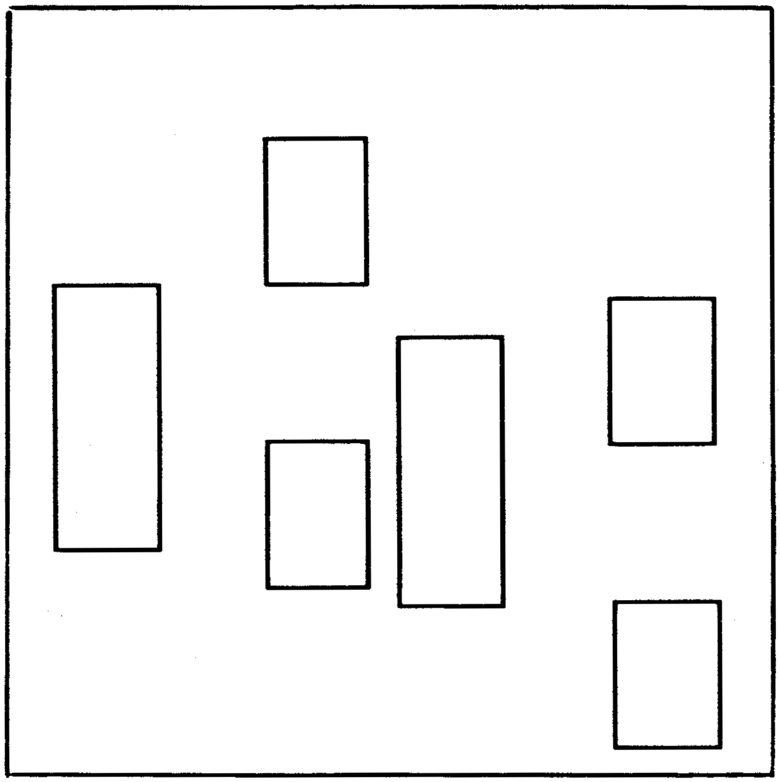


Figure 14. Twin-T Filter Dielectric Mask No. 3

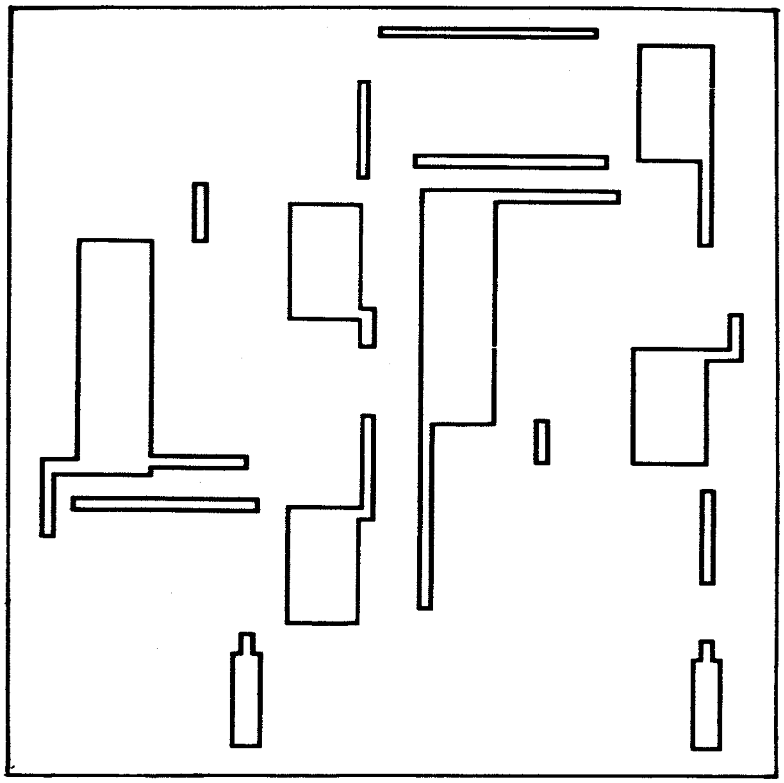


Figure 15. Twin-T Filter Second Conductor Mask No. 4

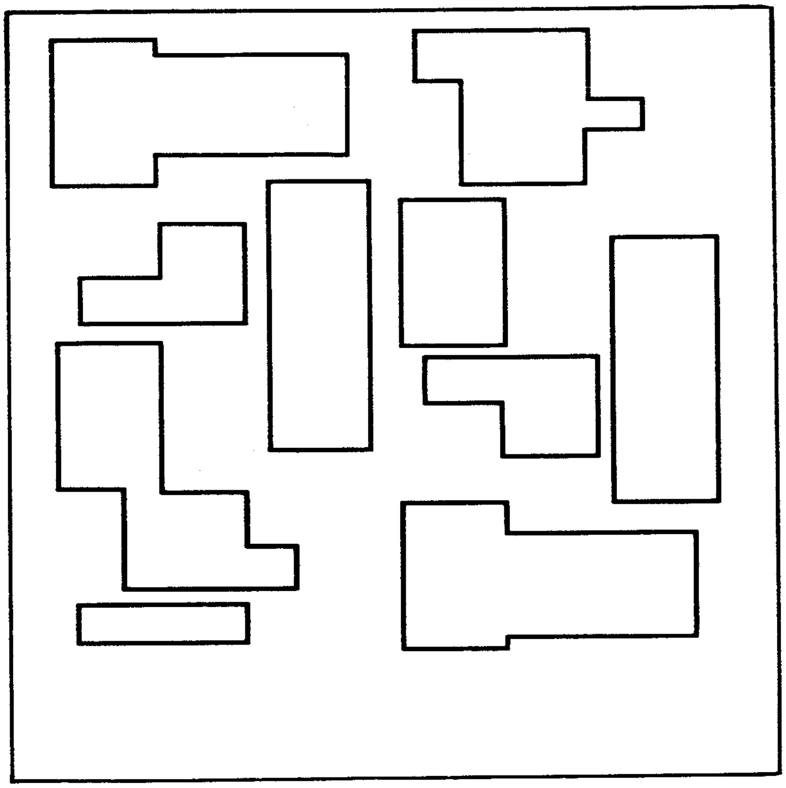


Figure 16. Twin-T Filter Protective Coating Mask No. 5

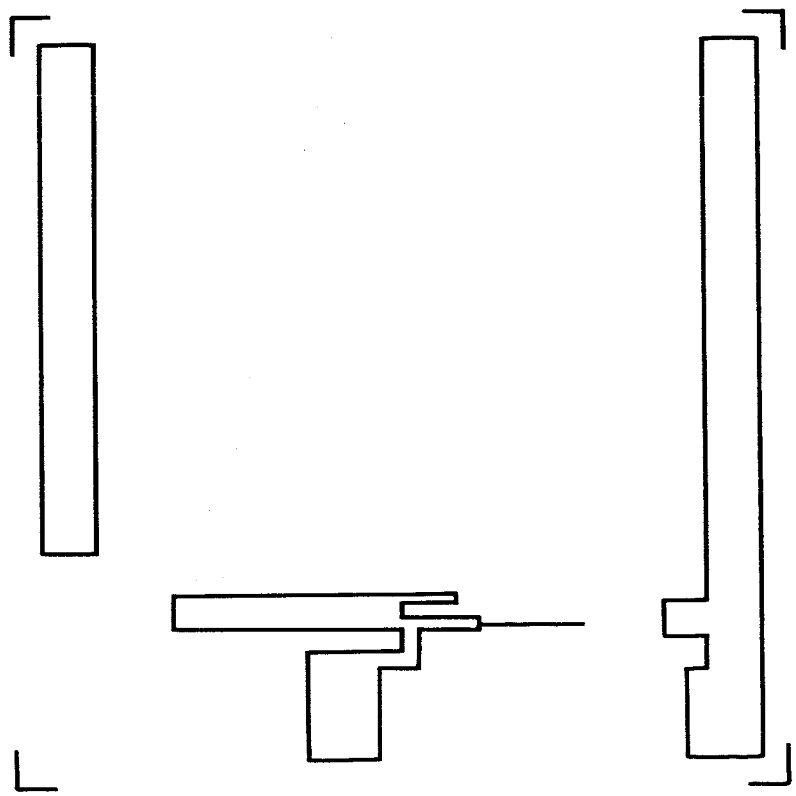


Figure 17. Diplexer-Transmitter End First Conductor Mask No. 1

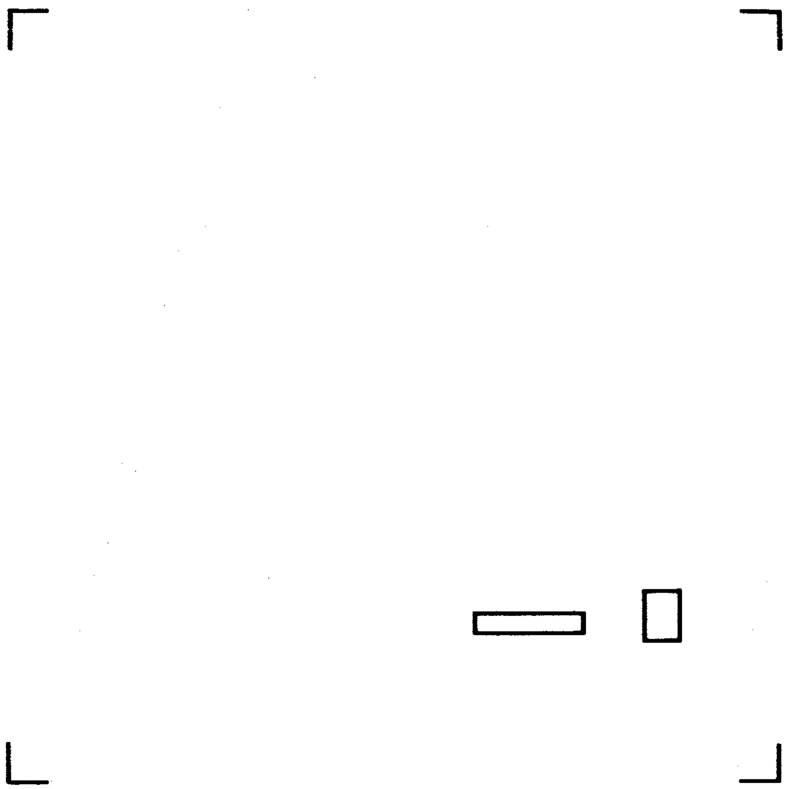


Figure 18. Diplexer-Transmitter End Dielectric Mask No. 2

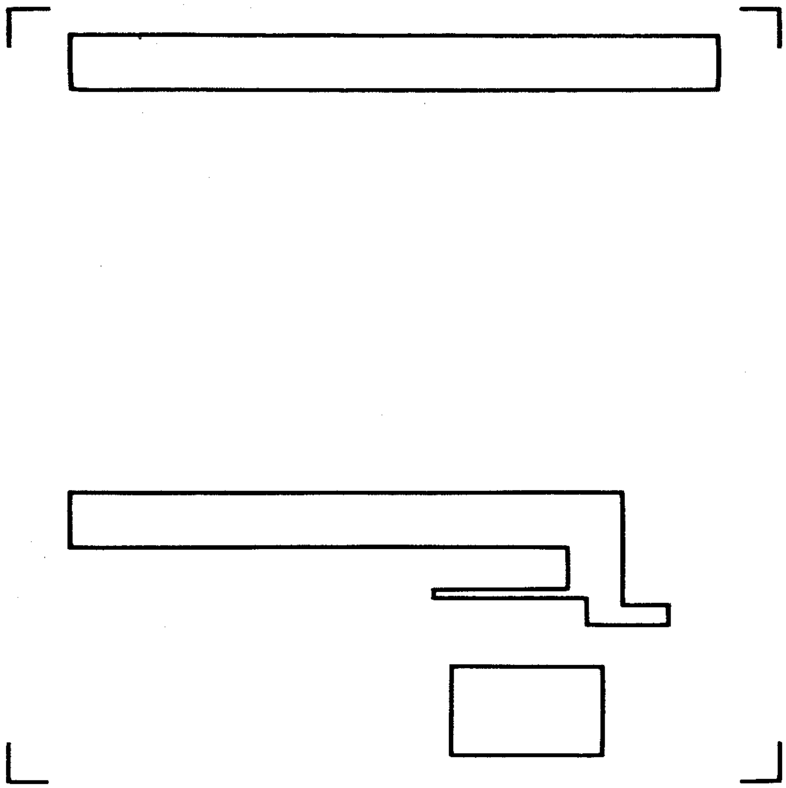


Figure 19. Diplexer-Transmitter End Second Conductor Mask No. 3

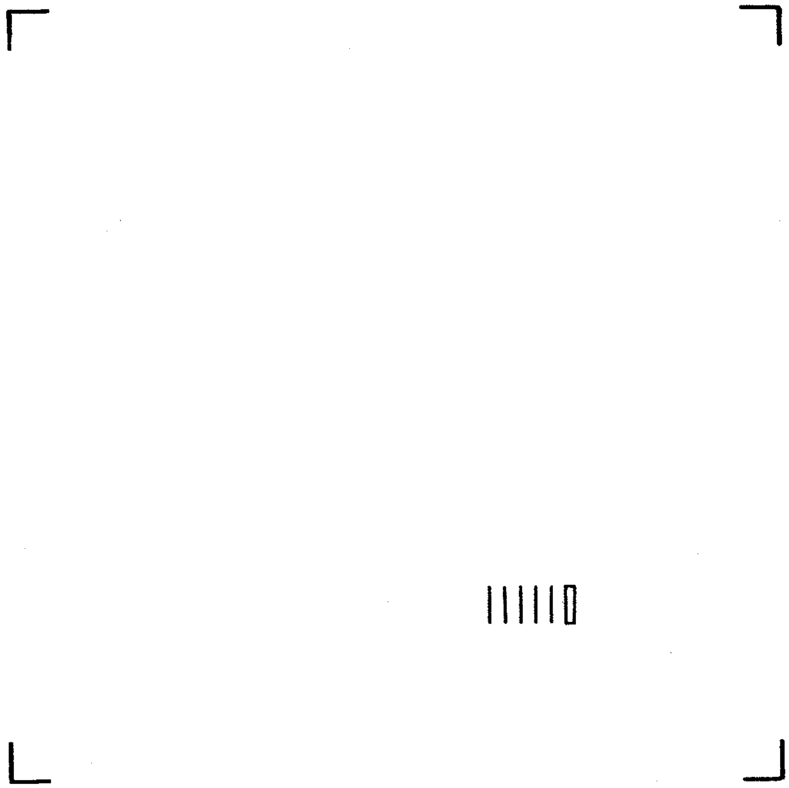


Figure 20. Diplexer-Transmitter End Capacitor Trim Plates Mask No. 4

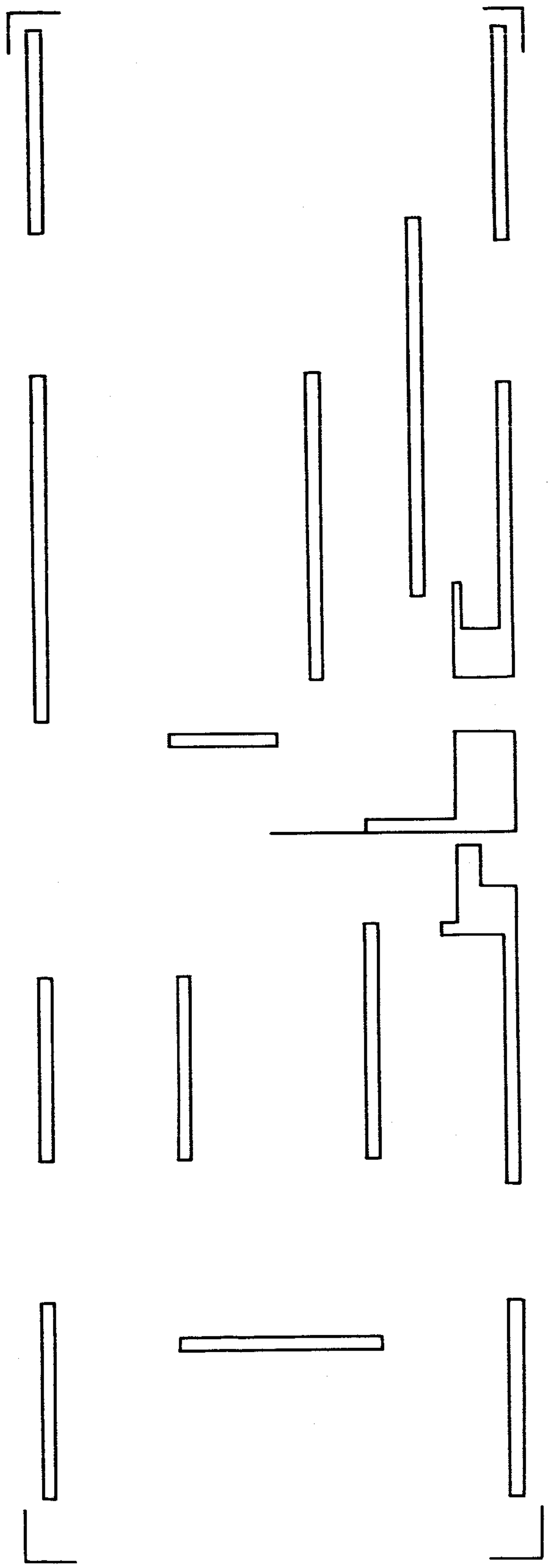


Figure 21. Diplexer-Receiver End First Conductor Mask No. 1

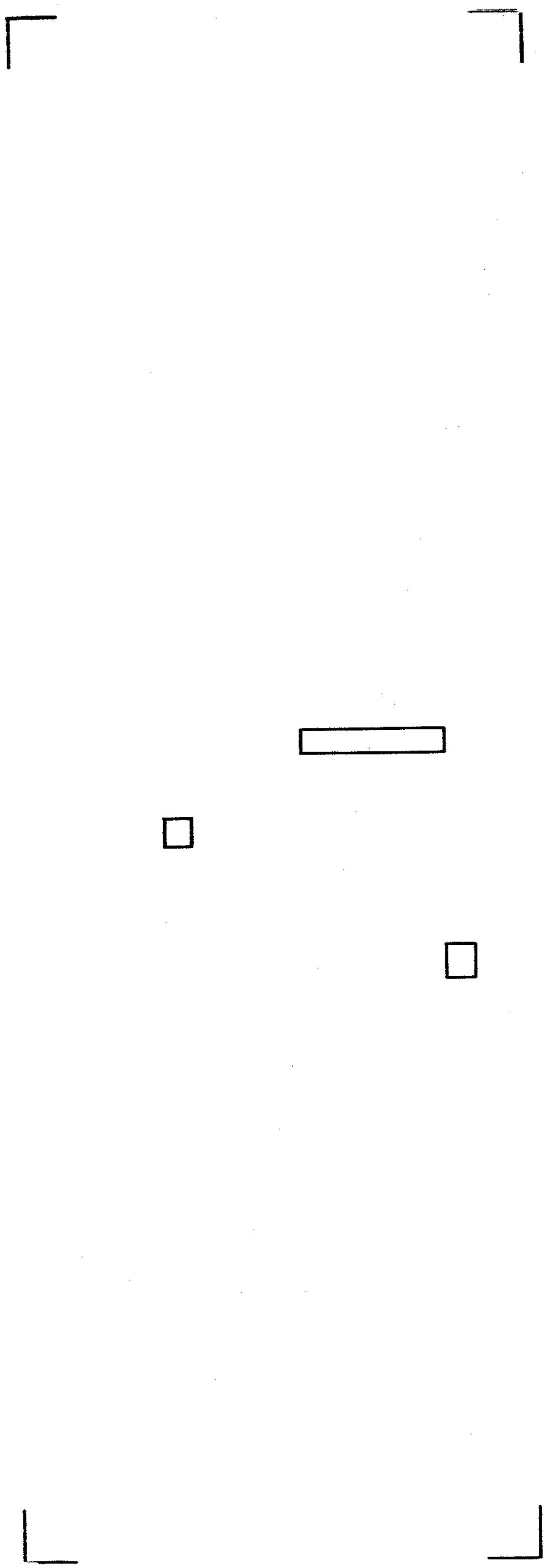


Figure 22. Diplexer-Receiver End Dielectric Mask No. 2

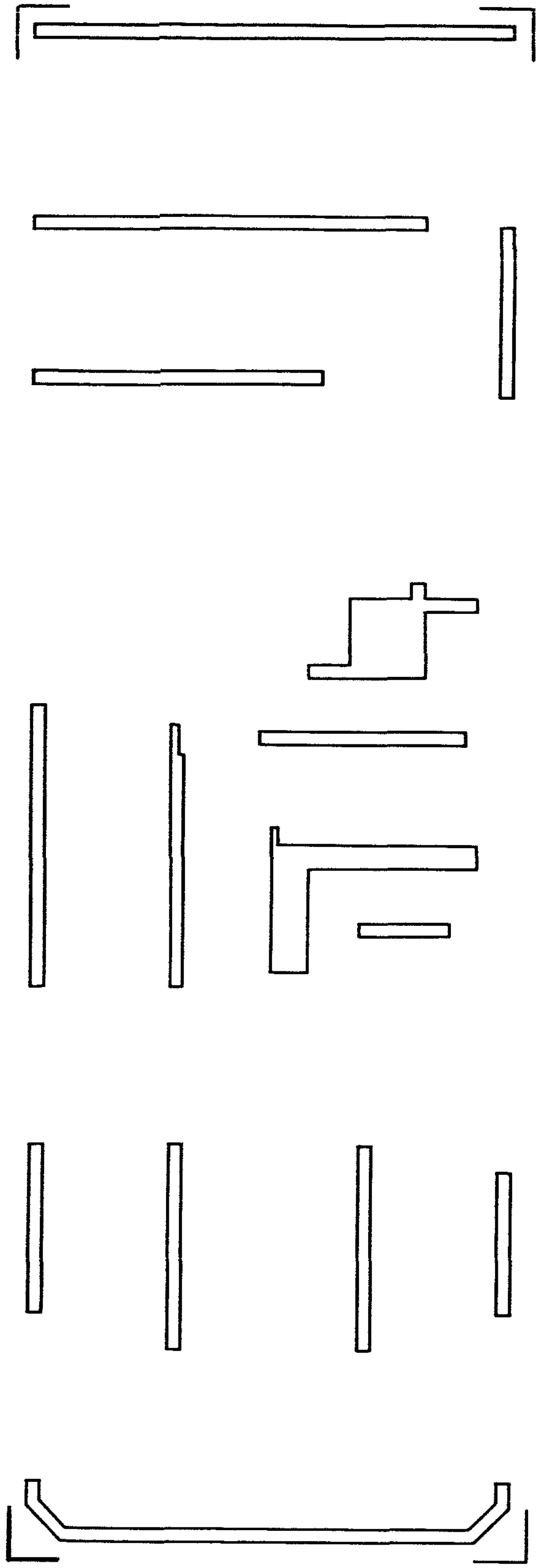


Figure 23. Diplexer-Receiver End Second Conductor Mask No. 3

Figure 24. Diplexer-Receiver End Capacitor Trim Plates Mask No. 4

7. VCO AND FILTER SUBSYSTEM

7.1 General Description

A block diagram of the VCO and filter subsystem appears in figure 25. The first VCO channel (nominally 4 kc), passes through two cascaded notch filters. These filters attenuate the second and third harmonics which, unattenuated, would appear as interfering signals in one of the higher frequency VCO channels. The second channel passes only through a second harmonic notch filter since the third harmonic occurs outside of the VCO subsystem passband. Channels 3 through 7 are left unfiltered because all of their harmonics occur outside the subsystem bandwidth.

The output of the 7 subcarrier channels are combined in a resistor summing network composed of R_1 through R_7. Amplifiers A_1 and A_2 compensate for the insertion loss, at the fundamental frequency, of the notch filter networks. Amplifiers A_1^1 through A_7^1 are voltage followers which isolate the individual VCO networks from each other as well as provide low output impedence drives for the resistor summing network.

A resistor combining network was chosen because of its simplicity and linear summing properties. An alternate solution might have been to use an operational amplifier summing network, in which case amplifiers A_1 and A_2 could have been eliminated. A_1 and A_2, however, are simple one-stage amplifiers and are much easier and cheaper to construct than the operational amplifier which would have been required.

7.2 Subsystem Performance

Figure 26 is a strip chart recording of the frequency spectrum in the subsystem passband. The recording was made by connecting a Hewlett Packard

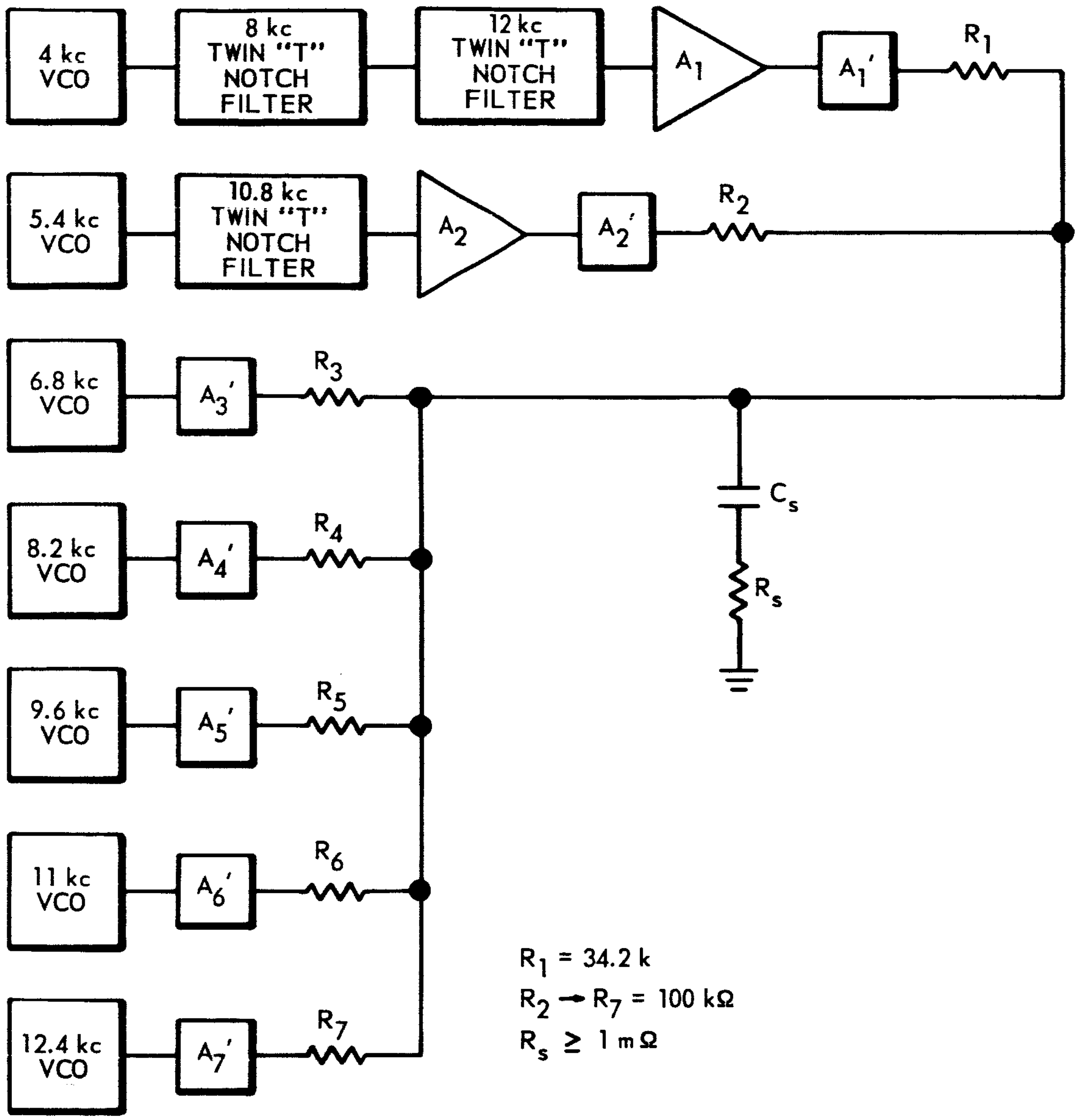
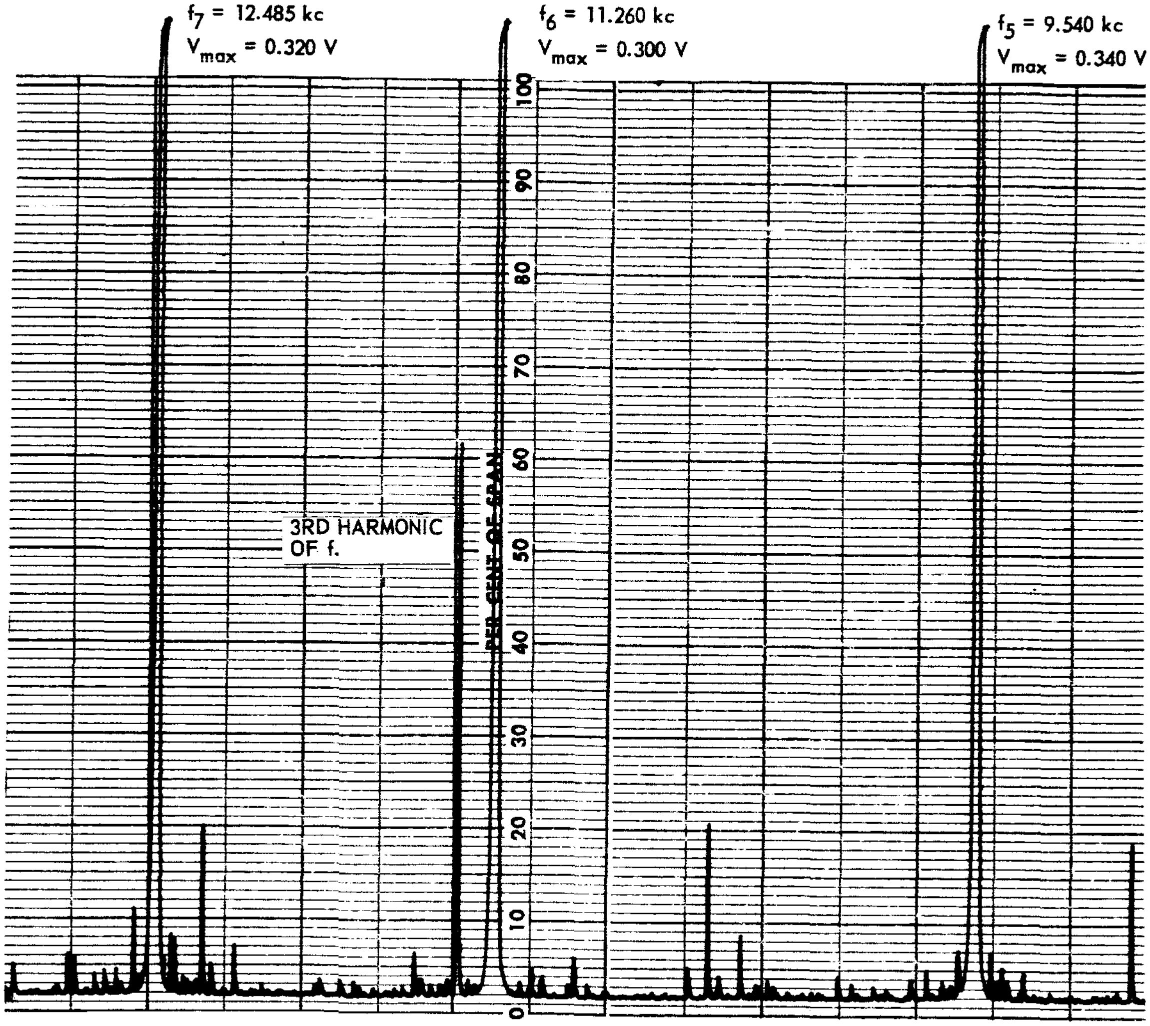


Figure 25. Black Diagram of VCO and Filter Subsystem


f7 = 12.485 kc
Vmax = 0.320 V
f6 = 11.260 kc
Vmax = 0.300 V
f5 = 9.540 kc
Vmax = 0.340 V
3RD HARMONIC
OF f.
PER CENT OF SPAN
0
10
20
30
40
50
60
70
80
90
100

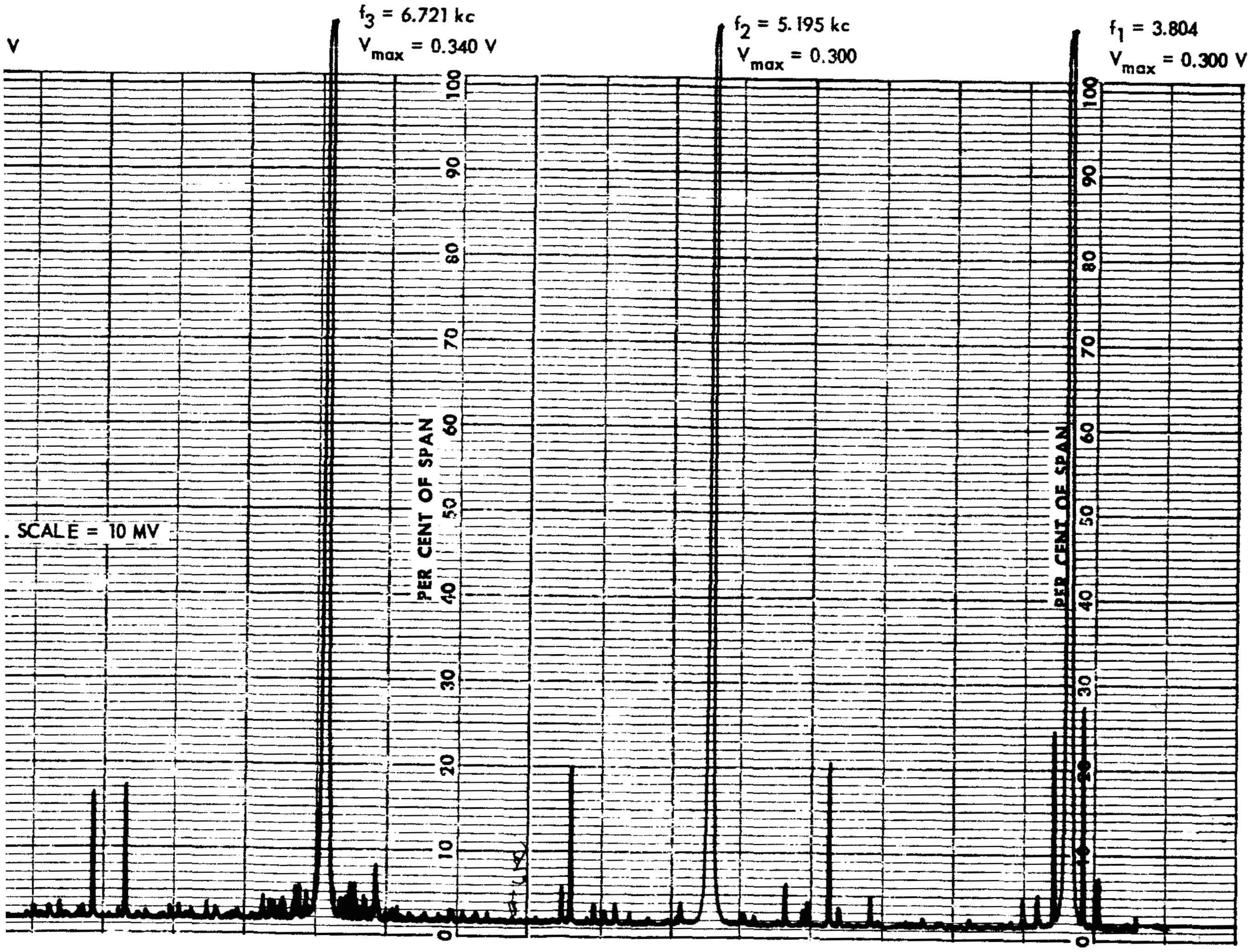


Figure 26. Frequency Spectrum of VCO and Filter System

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302A wave analyzer with a 297A sweep drive to the summing point (i.e., the common connection between resistors R_1 through R_7). The readings were made using 10 millivolts full-scale in order to record accurately small levels of spurious response. The full amplitude of the fundamental VCO signal is recorded on the figure and varies roughly between 300 and 340 millivolts; thus all spurious response below 3 millivolts is at least 40 db down from the fundamental. The variation in fundamental amplitude is a result of the variation in resistor values from those calculated. The nearest value 10% resistors were used in the construction of the summing network. In the plot shown, the third harmonic of the first channel is the only interfering signal above 3 millivolts (6 millivolts) and was subsequently reduced to 2.8 millivolts by adding a single stage RC low-pass filter to amplifier A_1.

In the subsystem shown, frequencies out of the passband are not attenuated and will modulate the transmitter. This undesirable extraneous modulation can be eliminated without degrading system performance by a set of simple, passive RC filters in the VCO outputs.

The VCO and filter subsystem operation has been suitably tested in breadboard form and is ready to be fabricated in thin films.

8. PACKAGING

8.1 Development of a Conformal Coating

Two types of conformal coatings are being investigated for use in the packaging of the thin-film devices. The function of the conformal coating will be to provide both a moisture vapor barrier and mechanical insulation to protect the device against harmful atmospheric components and external mechanical stresses, respectively, and to avoid reliance upon a hermetically sealed external package. The two types of conformal coating materials under consideration are Apiezon Wax and compliant (elastomeric), low temperature-curing silicone compounds.

8.2 Apiezon Wax

This material is an extremely low vapor pressure hydrocarbon wax obtained by molecular distillation of a selected petroleum fraction and is used extensively for high vacuum seals. It is produced by Shell Oil Co. and sold by James C. Biddle Co., Plymouth Meeting, Pa. Three twin-T modules have been coated with Hard Wax W, an opaque black material with a softening temperature range of 80-90°C. The coating was applied in a vacuum chamber by placing a small quantity of the solid wax, which had been previously deaerated by melting under vacuum, on the surface of the device heated to just above 100°C on a hotplate. At this temperature, the wax melted and flowed over the surface of the thin-film circuit to form a thin, adherent, uniform, void-free coating which subsequently solidified on cooling. The conformal coatings so applied did not affect the performance of the devices when they were tested in the laboratory atmosphere over a period of several weeks.

8.3 Compliant Silicone Coating

Coatings based upon elastomeric silicone potting and encapsulation compounds are advantageous from several standpoints. First, these materials provide outstanding protection against moisture; and secondly, they cure at low temperatures to soft, rubbery, resilient solids with very little shrinkage, being applied as viscous liquids. Their operational temperature range is considerably higher than that of Apiezon Wax. Such coatings have been found to appreciably reduce embedment and other external mechanical stresses on encapsulated delicate electronic components. The following coating materials have been obtained for investigation:

G. E. RTV-602 Silicone Potting Compound

G. E. RTV-615A Silicone Potting Compound

G. E. SS-4090 Electrical Insulating Coating

Dow Corning Sylgard 51 Dielectric Gel

These latter compliant materials appear very attractive for use in conjunction with a rigid external flat pack.

8.4 Development of a Rigid External Package

Plans for the development of a rigid external package (flat pack) for the thin-film devices are based upon the use of a thermoplastic material for the outer case, in which the leads will be firmly embedded. The thin-film device will be connected to the leads inside this case, coated or encapsulated with one of the above-mentioned conformal coating materials, and the case subsequently sealed.

9. SUMMARY

Phase B of the project is on schedule, with the system design essentially complete and the individual modules identified. A set of twin-T filters has been fabricated and is now being evaluated. A diplexer and a VCO design are complete in thin-film form and the masks are now being prepared. A packaging study has been initiated with emphasis placed on a conformal coating.

During the next quarter most of the modules will be in the thin-filming process. Component stability will be studied as a function of both packaging and temperature. Finally, the evaluation of the diplexer substrates should provide the necessary information for thin-filming the RF portions of the transceiver.